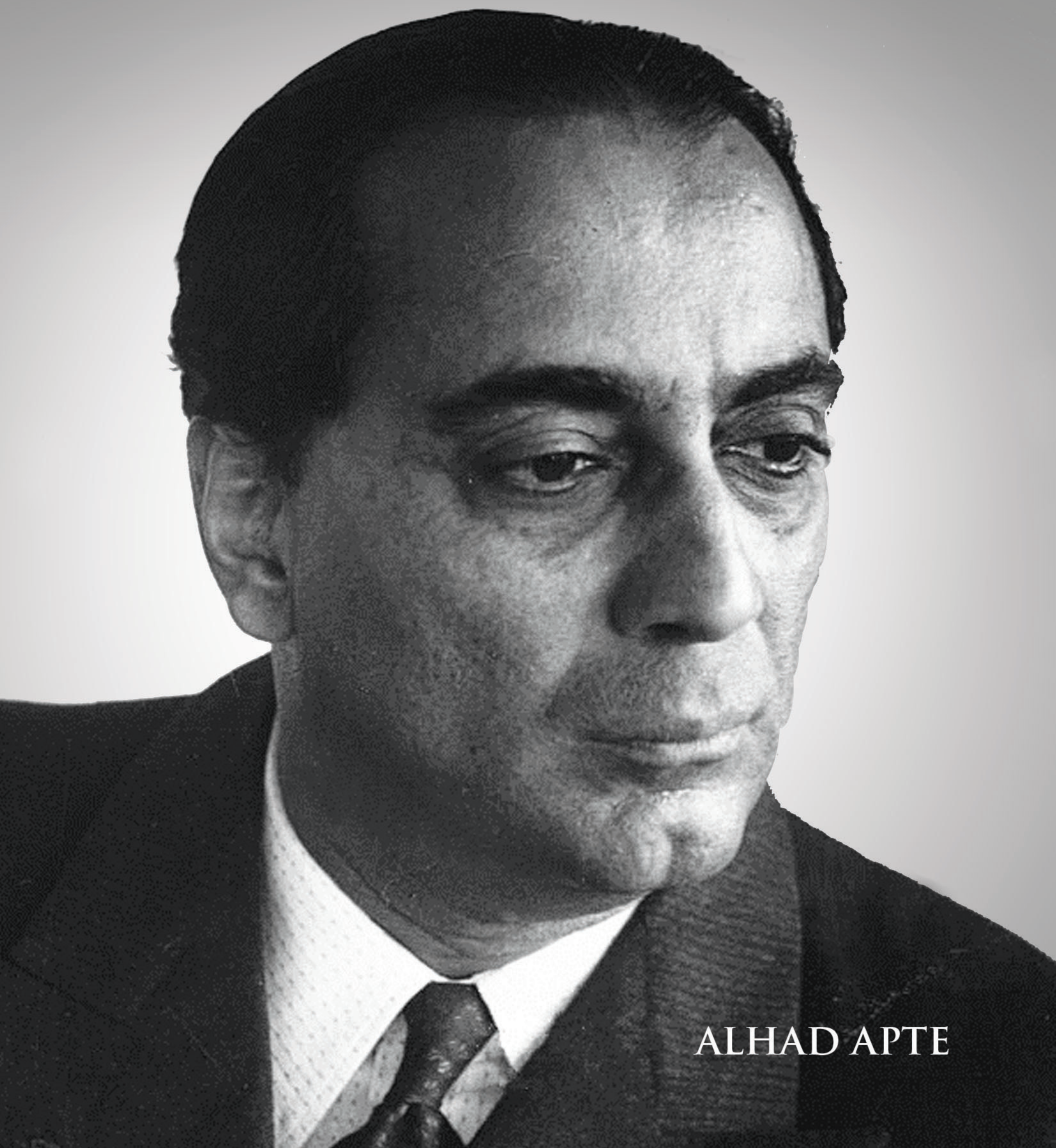
HOMI BHABHA

THE FATHER OF INDIA'S ATOMIC ENERGY PROGRAMME



ALHAD APTE

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August 2017

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Early Days

"I seriously say to you that business or job as an engineer is not the thing forme. It is totally foreign to my nature and radically opposed to my temperament, and opinions. Physics is my line....."

"My success will not depend on what A or B thinks of me. My success will be what I make of my work."

"Besides, India is not a land where science cannot be carried on."

"I am burning with a desire to do physics. I will and must do it some time. It is my only ambition. I have no desire to be a successful man or the head of a big firm....."

"How can anybody else know at what time what one will do, if there is nothing to show? It is no use saying to Beethoven 'you must be a scientist, for it is a great thing', when he did not care two hoots for science; or to Socrates 'bean engineer; it is the work of an intelligent man'. It is not in the nature of things."

"I therefore earnestly implore you to let me do physics".

These are the words penned down by the great visionary Indian scientist of the twentieth century, Dr. Homi Jehangir

With parents and brother Jamshed

Bhabha, in a letter he wrote to his father on 8th August 1928. He was, then, studying at Cambridge University in England. Let us see why Dr. Bhabha considered writing the letter very important. First, about the family he was born in.

Homi was born in Mumbai (then Bombay), to a renowned lawyer, Barrister Jehangir Hormusji Bhabha and Meherbai, on 30th October 1909. His father, educated at University of Oxford in England, was the legal advisor to the Tata Group of Industries. His mother was granddaughter of Sir Dinshaw Maneckji Petit,a respected philanthropist, a person who took the view that humanity is the most important virtue.

His paternal grandfather too was a renowned and learned person. Hormusji Jehangir Bhabha was Inspector General of Education in Mysore State and was a highly respected person there. His paternal aunt Meherbai was married to Sir Dorabji Tata. The family also had a tradition of service to the country. The Tata family was frequently visited by many national leaders,

including Mahatma Gandhi, who were involved in freedom struggle. Homi Bhabha used to be around these patriotic personalities, since his childhood.

With such an environment in his early years, Homi Bhabha, an intelligent boy,grew into a precociously driven young man. He was serious minded, deeply loved his country,and had a high regard for knowledge and education.

2

Bhabha at Cambridge University

Homi Bhabha passed the Senior Cambridge examination from Mumbai at the age of 15. In 1927, he joined Gonville and Caius College in Cambridge University for his education in engineering. It is interesting to know that Homi's uncle Sir Dorabji Tata had also studied at the same college and had, later on, shown great generosity in donating £ 25, 000 to the college, which was a huge amount in those days.

Homi Bhabha's family desired that Homi study engineering at Cambridge,so as to make a successful engineering career possible,But Cambridge University in those days, as it is still today, was one of the great centre's for Physics research in the world and hosted some of the pioneering luminaries of the day. The Cavendish laboratory, in particular, was described as a Mecca of Physics,a ground zero for new and exciting discoveries of that period in frontier domains like electro-magnetism, Radio, Atomic Research, electricity,

Bhabha arrived there as a young pilgrim at Varanasi. He could not but be influenced by the rarified air of speculation, experimentation, pioneering spirit and the frontier culture of

science. Small wonder that Cambridge drew talented young men from Continental Europe, North America and Asia.

At his college, Bhabha came in close contact with the renowned physicist Paul Dirac, who was doing research in Theoretical Physics there and who, later, went onto to win the Nobel Prize in 1933. Nobel Laureate Lord Rutherford was Director of Cavendish Laboratory of Cambridge and was doing his research in experimental physics at Cambridge.

It took Homi Bhabha only one year at Cambridge to firm up his mind on what he wanted to pursue as his career. Though he had already undertaken his course in Mechanical Engineering, Physics attracted him tremendously. This realization, of his own self, prompted him to write the famous letter to his father, quoted at the beginning of this story. One can see intensity and firmness in what he wrote. His father had to yield to his wishes, at least to some extent. He changed his plan for his son a little. With the condition that Bhabha successfully cleared Mechanical Engineering Tripos, which is the Degree at Cambridge, his father promised him further two years at Cambridge to pursue Mathematics.

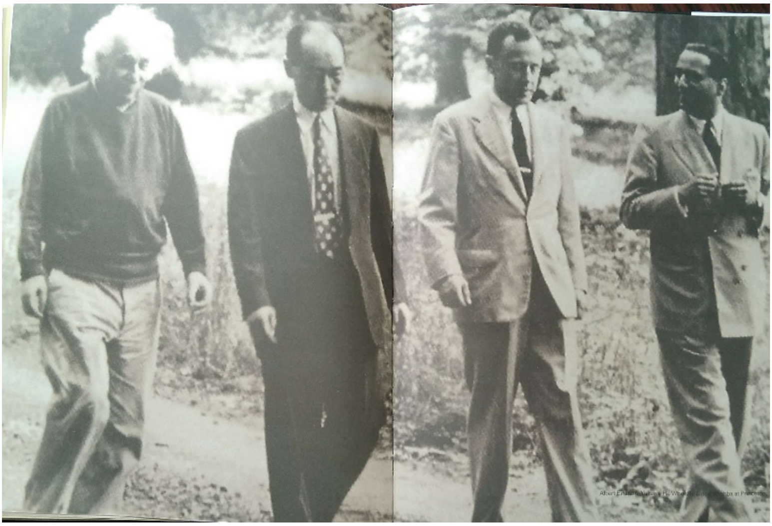
Bhabha seized this opportunity with open arms. He not only passed the Tripos in Mechanical Engineering with First Class in 1930, but also obtained First Class in Mathematics Tripos two years later. His interest in Physics was so keen, that he pursued, in parallel, his Ph.D. research work in Theoretical Physics at Cambridge, with Wrangler Ralph H. Fowler as his Doctoral Advisor. His physics research in theory of'Cosmic Shower' earned him his Ph.D. Doctorate in 1933. One can see the amazing academic achievements of Homi Bhabha in his five years study at Cambridge. This is the proof of his tremendous talent, hard work and perseverance.

Bhabha's research at Cambridge

Homi Bhabha continued his research work in Physics. His good performance in the Mathematics Tripos earned him the Rouse Ball Travelling Studentship. This enabled him to visit other important research centres in Europe. He, then, split his time between further studies at Cambridge and his visits to other research laboratories in Europe. He first visited Copenhagen in Denmark to do his studies in atomic physics with the Nobel Laureate Niels Bohr, an original mind who made ground breaking contributions to the understanding of atomic structures and quantum theory. Besides that he was a great mentor and many leading Scientists of the era, including the famous Werner Heisenberg. He then proceeded to Zurich, Switzerland to work with another giant in the physics community,Wolfgang Pauli. In early 1934, he went to Italy to work at Enrico Fermi's Institute of Physics in Rome. Both Pauli and Fermi would receive Nobel Award, Fermi in 1938 and Pauli in 1945.

In 1935, Bhabha published his work in the study of scattering of tiny elementary atomic particles. In honour of his contribution to Particle Physics, his work got known as 'Bhabha Scattering'. In 1936, he visited the Wills Physical Laboratory at Bristol and worked with a senior scientist, Walter Heitler. With Heitler, Bhabha developed a theory that is now famous as 'Bhabha-Heitler Cascade Theory'. These achievements earned Homi Bhabha a permanent place in physics text books on Cosmic Rays.

While doing the research work in physics at Cambridge, Bhabha's personality displayed several aspects. He was good at Arts. He was an excellent painter and sketch artist. In fact, he would have been an accomplished painter had he not turned a physicist. He was connoisseur of western music and well understood Indian Music too. He was a poet and was



With Einstein, Hideki Yukawa, John Wheeler

good at designing stages for plays. He was quite good in the building architecture and landscaping. James Chadwick, who was awarded Nobel Prize in 1935 for discovery of the particle 'neutron', once wanted to fill a post of Reader in Theoretical Physics at Liverpool in England. He had approached Bhabha for the post, but finally decided not to engage him. He himself explained the reason for it. "Bhabha was too good. The post would be drudgery to this most exceptional man. He had extremely wide interests...not merely interests but far more than that. However much I like him, it would not be fair to him."

With his full involvement in the Cambridge activities and the reputation that he started establishing within the scientific circle, Bhabha was passionately pursuing the path in Physics that he wanted so strongly. By this time he had received the Royal Society grant to work at Manchester in the laboratory of P. M. S. Blackett. But this was not to be.

3

Return to India

It was the year 1939 that changed Homi Bhabha's career path significantly. He was about to take up the research work at Manchester. But, before going to Manchester, Homi Bhabha came to India on a vacation. While he was enjoying his vacation, World War II broke in Europe. This brought about a drastic change in all walks of life, and science was no exception. Normal scientific research in the United Kingdom and other countries in Europe came to a grinding halt. Scientists were diverted to war related research. Friendship among scientists world over was on decline.

In this grave situation, Bhabha could not return to England. He had to watch the situation and wait for it to become normal . He wanted to make the best use of his extended vacation. He had a lot of unfinished work at Cambridge. It was more mathematical in nature. Hence, it was possible to complete it and take it to a finished form in India.

A number of universities and institutes in India were eager to invite Bhabha to lecture on his specialization, namely, Cosmic Ray Physics. The subject consists of the study of extremely penetrating rays coming to earth from outer space, even beyond solar system. He was happy to deliver the lectures, where he


Launching Cosmic Ray Telescope with balloons at Bengaluru

got the opportunity to meet Indian scientists and learn about their research.

It was during this period that he established rapport with the Indian Nobel Laureate Sir C. V. Raman, who, at that time, was heading the Physics Department of the Indian Institute of Science, Bengaluru. Bhabha joined Indian Institute of Science and continued his research in cosmic rays there.

Work on Cosmic Rays

Bengaluru is one of the few places in the world, where it was possible to study cosmic rays near the equator. As it is close to the geomagnetic equator, it has certain advantages in the study of cosmic rays. But then there came the question of high aerial flying of the equipment. Rubber balloons for flying the equipment for experiments were not available. It was a problem difficult to solve, but not unsurmountable for Bhabha. It was the Second World War period. High flying aircrafts of US Air Force were stationed at Bengaluru. Bhabha got the idea of flying his equipment on those aircrafts. With his persuasive skills, he managed to get permission for sending his telescopes on these aircrafts up to heights of about 30,000 feet. In December 1944, two flights were arranged. Experiments were conducted at various altitudes,ranging from 5,000 to 30,000 feet.

Sir C.V. Raman had high regard to the multifaceted capabilities in Bhabha and called him 'a truly renaissance man', which meant 'a man limitless in his capacities'. C.V. Raman took initiative in getting Bhabha the prestigious fellowship of the Indian Academy of Science. Raman, himself a fellow of the Royal Society of London, recommended Dr. Homi Bhabha also for the world reputed fellowship of the Royal Society of London. Bhabha received the fellowship in 1941.

While Bhabha continued his research work in Physics to the best of possibility in the Indian conditions, the person in him was steadily undergoing a change. Having spent his twelve

youthful years in England, he was a little detached from the scientific, social and political realities of India. After returning to India, he had the opportunity to travel widely in the country for the purpose of delivering scientific lectures. He came in contact with a number of Indian Scientists and knew about the scientific work in the country.

Change of track

In addition to having a finely tuned antenna for the current developments in Physics and Science in general, Bhabha was sensitive to the various currents in the social and political life of India. His impressionable years having been spent in the company of many high minded and patriotic people, Bhabha was quickly able to grasp the direction of the country. Decolonization was the wave and the Indian people would soon be free from British rule. His broad view however informed him that freedom would amount to little unless the country quickly achieved scientific progress. Only that could make the country strong and secure in the future. Scientists he knew would have to play the part. In addition, state power would have to be wedded to scientific research as only that would lead to accelerated research and development for overall economic and industrial development of the country.

During his stay in Bengaluru, he joined a cultural group. Its members included Mrinalini and Vikram Sarabhai. Mrinalini, a classical dancer from Kerala, was the sister of Captain Laxmi Sehgal of Azad Hind Sena founded by Netaji Subhash Chandra Bose. This was another contact for Bhabha with both, India's freedom struggle and arts. Sarabhai, who was ten years younger to Bhabha, was also a Ph.D. student at Cambridge. He too, like Bhabha, could not continue there due to the war. He, then, obtained special permission from Cambridge University to

continue his experimental work at Bengaluru under Sir Raman's general guidance. Sarabhai went to England for completing his Ph.D. in 1945 and returned in 1947 after completing the same. Bhabha and developed mutual friendship and remained friends all along. In Bengaluru and in Mumbai, Bhabha also came in contact with several liberal persons with socialist inclination. Socialism was in vogue in those days and was seen as a panacea for a struggling nation like India.

Another strong personality in that period was Pandit Jawaharlal Nehru. He was a anglophile lawyer, author, nationalist and left leaning thinker, a heavy weight of the Congress Party. Bhabha had made acquaintance with Nehru in 1937, when they met on a tour of Europe. In addition to a European education and English manners, both shared deep nationalistic convictions and concrete ideas of India's future. Nehru in particular, despite his non-technical background, deeply appreciated the importance of science, technology, research and cutting edge industry in solving many of India's social and economic problems. This would later translate into a warm friendship and close partnership after Nehru became Prime Minister.

While Bhabha was doing his physics research in Bengaluru, he was closely watching developments of freedom struggle and the role Jawaharlal Nehru was playing in that. Both would have dreams of fast developing independent India. While at Cambridge, Bhabha was impressed with the thoughts expressed by Physicist J.D. Bernal. Bernal used to say that Science was bringing about changes in the society and believed that Science had its firm roots in society. The benefits of science, therefore, should reach entire society. They should not remain limited to rulers. Bhabha's thoughts started revolving on how he could contribute to the scientific developments in India. In his younger age, Bhabha turned from engineering to theoretical physics.

After returning to India and watching social and political environment in the country, his thoughts started encompassing wider domain rather than just being satisfied with physics.

It was exactly during this period that new revolutionary knowledge was emerging in the field of nuclear physics, which was a part of atomic physics. Nucleus is the central part of atom. Therefore, whatever is 'nuclear' can also be called 'atomic'. But everything atomic need not be nuclear. In the decades of 1930s and 1940s, it was nucleus that was the focus. Dramatic events in the world of nuclear science were taking place on the world stage. The field of nuclear physics had taken a new turn after discovery of nuclear energy that can be tapped for human use.

4

Beginning of Atomic Research in India

In 19th century, scientist John Dalton had put forward his theory that all the matter is made of small particles, atoms, which are further indivisible. In the beginning of twentieth century, Ernest Rutherford, working at Cambridge, and then Niels Bohr, working at Copenhagen, established that atoms were not indivisible. They showed that they have a positively charged central nucleus, with concentrated mass, and tinier electrons revolving around it in certain orbits. It was proved by James Chadwick that, in addition to electrically positively charged particles called 'proton' that were present in nucleus of all the atoms, the nucleus of some atoms contained electrically neutral particle(s), named as 'neutron'. These scientists, who were leading research in atomic science, were Bhabha's peers, while he was at Cambridge. Bhabha developed warm relationships with several top scientists who were engaged in the research in the field of atomic physics. He, himself a particle physicist, added his discoveries to the theory of elementary particles.

In 1939 it was shown that if certain heavy atoms, like uranium, are bombarded by neutrons of high energy, their

nuclei split into fragments, releasing large amount of energy. Enrico Fermi later showed that this energy releasing reaction can be controlled, in such a manner that it continues as a chain reaction, releasing energy at a steady rate. With this invention, Enrico Fermi built first very small American nuclear reactor for generating energy, in 1942, for demonstration purpose. It was only in 1955 that the first nuclear reactor supplied electrical energy commercially. Unfortunately, in the fever of the World War, the destructive atom bomb was built,based on the same theory, and was dropped on Japan in 1945, before the constructive nuclear reactors were built.

Dr. Homi Bhabha, who was carrying out research in cosmic rays in Bengaluru,was keeping track of developments in the field of nuclear physics. His interest, of course, was in the constructive aspects of nuclear energy. He was looking at nuclear energy for producing electricity. He was watching the developments in this field taking place world over. Research in building nuclear reactors was going on in America, England, France, Canada and Russia. Just as Bhabha had acquaintance with Fermi who was building American Reactor, he knew Sir John Cockcroft who also was at Cambridge when Bhabha joined Cambridge. Sir Cockcroft was the scientist who was building British nuclear Reactor and Bhabha was familiar with his work. It was Sir Cockcroft who also started nuclear programme in Canada. Later he handed over its charge in 1946 to Bennett Lewis, another Cambridge student and a close friend of Dr. Bhabha. Thus, the entire international circle of leading scientists, who were engaged in nuclear energy research for production of electricity were well known to Dr. Bhabha.

Dr. Bhabha realized the vital importance of nuclear energy to produce electricity and how useful it would be for a developing country like India. Electricity is the driving force for development of any nation. As Bhabha used to say “no energy

is costlier than 'no energy' ", which means that if you do not have sufficient electrical energy, the development is going to be much more costlier. He was firm in his belief that nuclear energy would provide the necessary source in long run to generate electricity. At the same time he was noticing that the scientific publications on the subject had disappeared in that period, which meant that the scientists in America and Europe had diverted to secret projects in nuclear weapons.

The birth story of T.I.F.R.

The overall situation in the decade of 1940 convinced Dr. Bhabha that India had no option but to start her own research programmes in the field of nuclear physics. Bhabha, doing physics research at Bengaluru, had before him several research proposals in physics to continue his research. Several organizations in the country were desiring him to be with them. But Bhabha's thoughts were much broader and contextual. He was thinking of the state of science and technology in the country and ways to bring its level at par with that in the developed nations. He was considering seriously about venturing fast into the field of atomic energy, so that large gaps seen, between India and the developed nations, in other fields of science were closed by rapid Indian strides in this new and challenging field.

In 1943 he wrote the now famous letter to J.R.D. Tata in which he mentioned that he had thoughts of going back to Cambridge. However, if suitable facilities were made available he was ready to continue in India. He expressed that it was one's duty to stay in one's own country and build up schools of science comparable with those in other lands. He also opined that lack of proper conditions and intelligent financial support hampers the development of science in India. This was the

reason why the development could not take place at the pace which talent in the country would warrant. J.R.D. Tata sensed the genuine desire of Homi Bhabha to uplift science research in India. He suggested that Bhabha or some of his colleagues might put up a concrete proposal to Sir Dorab Tata trust, who might respond favourably.

Bhabha accepted the suggestion and put up a well prepared proposal in March 1944 to the Sir Dorab Tata trust. It was not just a formal proposal, but contained guiding principles of scientific progress of the country and of establishing scientific institutes of high standard for that purpose. It was the first expression of the concept of nuclear programme of India. He firmly believed that, instead of the normal way of forming an institute or a department, and then searching for a person to manage it, it would be much more fruitful to identify a deserving person and build the institute around him. He also justified choice of Mumbai as the location of the institute.

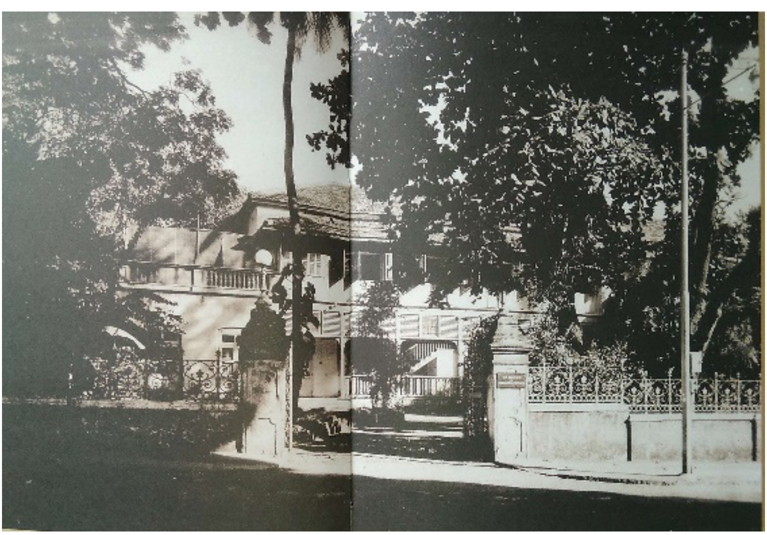
It is remarkable that Tata Trust approved the proposal in the next month itself. The Trustees decided that the financial and administrative help should be sought from the Government of Mumbai Province and the University of Mumbai. Bhabha agreed to it.

In the proposal made to the Tata Trust, Bhabha made a far reaching statement about human resources. He wrote, "when nuclear energy has been successfully applied for power production in, say, a couple of decades from now, India will not have to look abroad for its experts but will find them ready at hand." That showed the utmost importance attached by him to having country's own capable human resources. It also showed that he had plans for creation of human resources while building the proposed institute. Creation of quality human resources, indeed,played an important role in the progress made later on by the atomic energy programme of India. The self reliance of the programme is there for everyone to see.

He invited a number of talented persons to join his proposed institute. He called on his old Cambridge colleague, S. Chandrasekhar, who was then in the USA with the University of Chicago. He invited Dhramanand Kosambi, another mathematician from Fergusson College, Pune. Bhabha also called upon B.V. Srikantan from Bengaluru for Physics and R.P. Thatteworking with S.P. college, Pune for Electronics Discipline–'Radio Physics', as it was called those days.

The TIFR begins

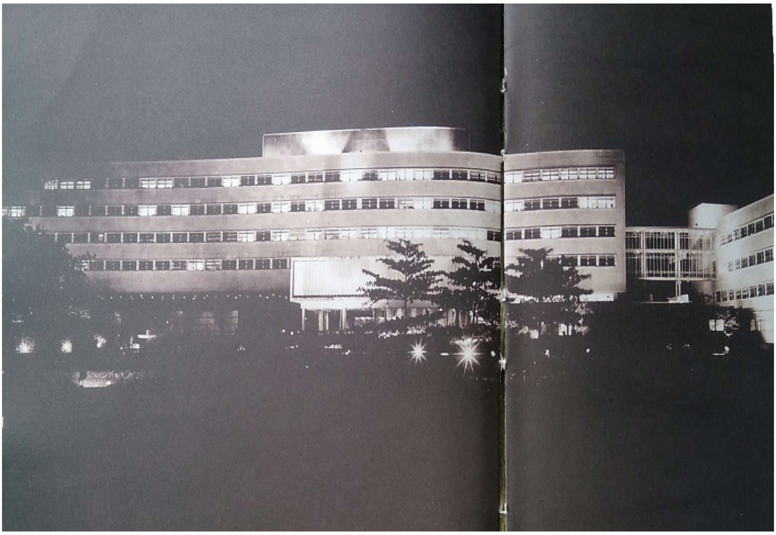
The new Institute began life on 1st June 1945 temporarily at Bengaluru, where Bhabha was doing his research. On 19th December 1945, it was shifted to Mumbai. On that day, it was inaugurated at the hands of Sir John Colville, who was the Governor of Mumbai. The institute, named as 'Tata Institute of Fundamental Research', TIFR for short, was started at the Kenilworth Bungalow on Pedder Road of Mumbai, which



Kenilworth Bungalow- TIFR's Birth Place

belonged to Dr. Bhabha's maternal aunt, Koovar Panday. Thus, the problem of finding a place was solved by Dr. Bhabha at least for a few years, till a proper location got ready. This arrangement continued till 1953. Some activities started shifting to a building named 'Old Yacht Club' situated near Gateway of India in Mumbai. Some laboratories were set up on Cadel Road in Mumbai. Finally in 1962, entire institute shifted to its own campus in Navynagar, Colaba, Mumbai.

Dr. Bhabha wanted to start research in many areas of use in developing atomic physics and related fields. He firmly believed that if we first make an institute and then look for scientists, you may not have proper persons to take the research on the correct path. He therefore identified capable persons in the respective fields first and then set up institutes or departments around them. This scheme of Dr. Bhabha has shown good results, because he located dedicated persons to take the lead. These persons further mentored many more capable persons to take the research ahead.



TIFR Building in Mumbai

Dr. Bhabha had dream of establishing an institute which would be of the same stature as that of the similar institutes in advanced countries. He wanted full support of the Government in establishing and running the institute. But at the same time, he wanted flexibility and freedom to manage the institute in such a way that would create proper research environment. He established Tata Institute of Fundamental Research along these lines. Today, the Institute is an internationally reputed research institute in fundamental science.

This was the period, when Bhabha had sown the seeds of atomic energy programme in India, while on one side continuing his research work as a physicist. TIFR became like a nursery to grow 'plants and trees' of Atomic Energy. In Bhabha's own words, "They were six very happy and fruitful years in my life."

It was, also, necessary to set up another institute for research in Nuclear Science and in Nuclear Engineering and Technology. For starting this process, the Atomic Energy Committee was set up in 1945. The ways of entering into the field of nuclear sciences were being discussed by the scientists who were members of the committee. Bhabha wanted to go very fast on this path and planned accordingly.

5

Establishing Atomic Energy Institutes

For designing and building systems for generating electricity from nuclear energy, a different institute was required, in addition to TIFR, which was set up for doing basic research. Bhabha recognised this need and made plans for setting up another institute for Nuclear Science and for Nuclear Engineering and Technology.

On 15th August 1947, India got independence from British Rule. Pandit Jawaharlal Nehru became the first Prime Minister of India. Plans were now put in place of realizing the atomic energy enterprise in the country. However, on nuclear science side, the environment was not very helpful.

The nuclear energy discovery was only 7-8 years old. Bhabha had a foresight to begin early and enter into the research field in nuclear domain within a few years of the discovery. In 1947, even the first nuclear reactor for generating electricity was yet to be built anywhere in the world. Science in India was not in its infancy, because of colonial neglect in the pre-independence era.. People proficient in science and engineering research were very small in number. Industry was not developed. Any

progress in the field was going to be an uphill task. It really required the genius of Homi Jehangir Bhabha and full support from the Government, even to plan the ambitious long term programme. This was where the synergy between Nehru and Bhabha helped tremendously.

Nuclear science is a very peculiar area from the point of view of necessity of proper handling of nuclear material. The energy that could be generated from the nuclei of atoms is very huge. Utmost care would be required to prevent its misuse in any form. The material is radioactive, which means it emits harmful radiations, which have to be confined in a closed volume. The material thus, required to be handled with care. Therefore, it was necessary that the technology was well controlled and regulated by the Government.

Government of India was very quick in preparing and passing Atomic Energy Act. This was done on 15th April 1948, that is, within eight months of getting independence. Obviously, Bhabha must have been a force behind this quick action. Significant amount of natural nuclear material was found in sands of Kerala seashore, which was under control of Kingdom of Travancore. The kingdom was yet to be a part of independent India. This also prompted to enact Atomic Energy Act quickly.

Within four months of passing the act, Bhabha could manage to establish 'Rare Minerals Survey Unit' in Delhi, on 10th August 1948. On the same day, a three member Atomic Energy Commission was constituted under Prime Minister.

Setting up the mother institute of Atomic Energy

Formation of Atomic Energy Commission paved the way for setting up the department for atomic energy. It would be

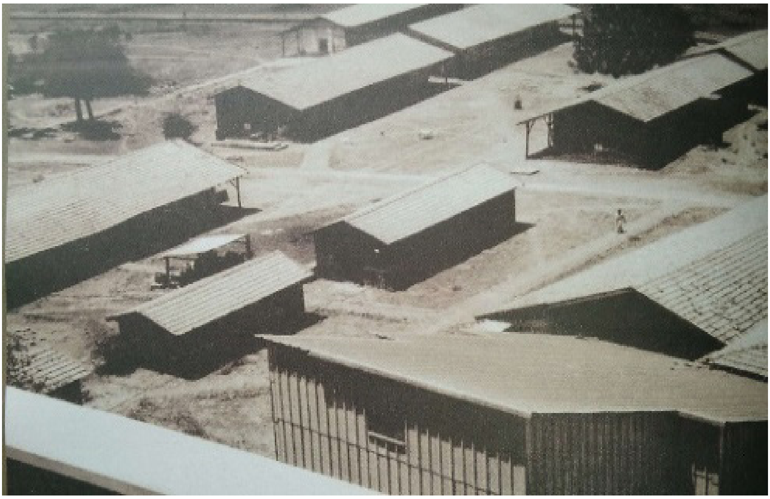
responsible for carrying out research activities, for building and operating nuclear power stations and for managing all other areas of nuclear science in the country. All the work under Atomic Energy Commission started at the Old Yacht Club building near Gateway of India. A new location was required to be identified for setting up research activities in all the areas of nuclear science and engineering. Bhabha surveyed various locations for this purpose and identified a beautiful area near Trombay village in East Mumbai for this purpose. The area was a 8-10 kilometer long land strip, enclosed between a tall hill on three sides and Thane creek, a few kilometer in width, on the fourth side. Work started there in 1954.

It was in 1954 that 'Department of Atomic Energy' was set up at the Old Yacht Club building, where the departmental head quarter was located. Setting up a separate department for atomic energy programme was essential because the magnitude of the functions to be performed was very large and because management and handling of nuclear materials needed special

Atomic Energy Headquarters at Old Yacht Club, Mumbai

type of expertise. The work of erecting various atomic research laboratories at the new site of Trombay was taken up under TIFR, the first research institute under the department at that time. The institute set up at Trombay in 1954 was named, 'Atomic Energy Establishment, Trombay', AEET for short. In the same year, he was awarded 'Padmabhushan' by the Government. Some temporary laboratories in the subject of Chemistry and Metallurgy started functioning in some old godowns on Cadel Road in Mumbai. This was in line with Bhabha's dedicated style of working, to start the planned work immediately and wherever possible, without waiting for a regular premises to be built.

Work of building independent India's Atomic Programme had begun at Trombay, administratively directed from Old Yacht Club and scientifically undertaken by scientists of TIFR. Bhabha started work simultaneously on all the fronts of the programme. The difference between nuclear sciences and other fields of science lies in the material used in nuclear field. It was essential to manage the material very carefully, so that it does not land into wrong hands. Hence, the first domain worked



Laboratories in sheds during TIFR construction

upon by Bhabha was locating, producing and processing of the material useful in nuclear fields, mainly the fuel to be used up in nuclear reactors. Reprocessing of the nuclear fuel after it is used up in reactors, for its reuse was a crucial part of it, so that the energy from fuel is extracted to the maximum extent and the fuel produces the least amount of radioactive waste.

Making of the first nuclear reactors of India

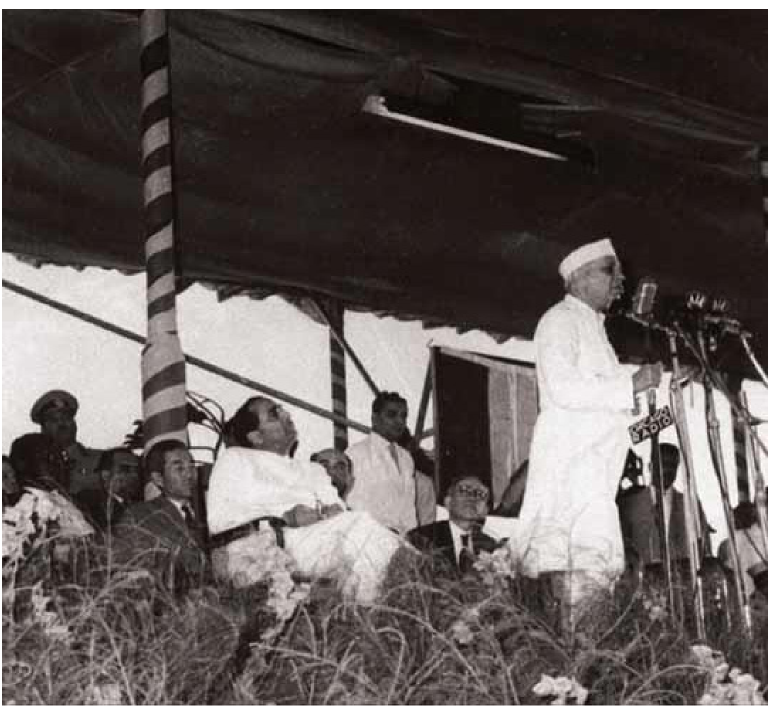
The next important job was to master the technology to build nuclear reactors. The first reactor in the world to supply electricity was built only in 1955. Bhabha showed tremendous courage and confidence in his colleagues to enter this new and difficult field, that needed management with a lot of caution and responsibility. He devised a three stage nuclear power programme specific to India. India has limited stock of Uranium, the major fuel for reactors. She has abundance in Thorium, which itself is not a fuel, but could be converted to reactor fuel. However, development of technology for using Thorium would take decades. Hence, it was necessary to start with Uranium.

Bhabha decided to use uranium in its natural composition. The type of technology using natural uranium was being developed by Canadians. Before entering any agreement with Canadians, he thought it appropriate to have experience in building a nuclear reactor on our own with any technology that was within our capability. That was how the first nuclear reactor of India, Apsara, was born in 1956. That was followed in 1962 by a reactor, later named 'CIRUS', with Canadian collaboration. These two were research reactors, not generating electricity. The agreement with Canada for reactors generating electricity followed. It was with the condition that the technology should be fully absorbed by Indians and be developed further on their

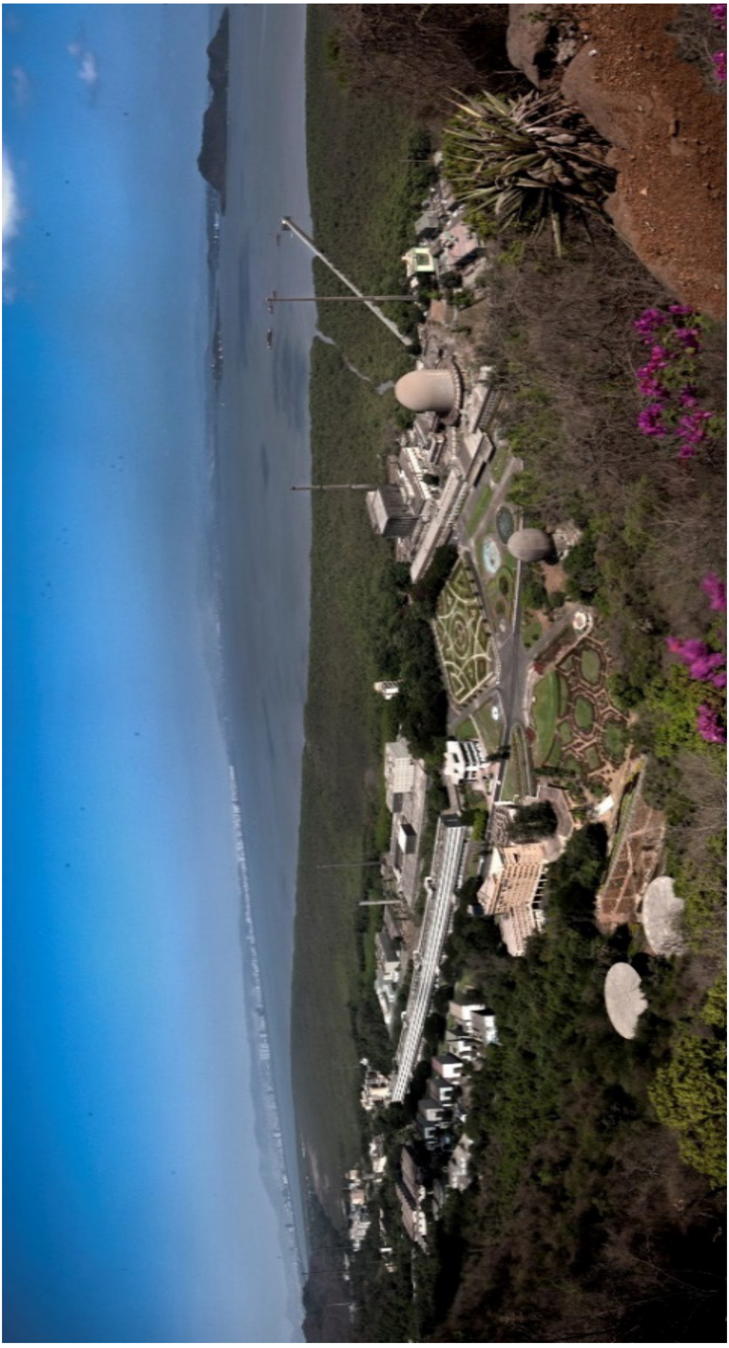
own. That is what happened later, during Bhabha's life and after. The technology, that uses natural uranium as its fuel, is India's mainstay even today, for nuclear power stations.

Reactors using natural uranium as fuel need to use a different variety of water called 'Heavy Water'. It is found in very small percentage, about 0.016 percent, in natural water. Hence, Bhabha started programme to manufacture Heavy Water, in which India is one of the largest producers today.

Before reaching the stage to use Thorium, it was necessary to take the intermediate step of making reactors using Plutonium as fuel. Plutonium is not available naturally and is required to be manufactured. These two technologies, making plutonium and making reactors using it has been achieved by Indian scientists



AEET Inauguration by Pandit Nehru in 1957



Bird's eye view of Bhabha Atomic Research Centre today

today. This is how India is progressing exactly along the path drawn by Dr. Bhabha, which shows vision and precise in-depth thinking of the man.

Research work for reactors is now carried out in two research centres in India. Bhabha Atomic Research Centre, BARC for short, in Mumbai, established in 1957 and named so after Bhabha departed from this world, and Indira Gandhi Centre for Reactor Research, IGCAR for short, at Kalpakkam in Tamil Nadu, established in 1971.

Bhabha also was quick to start research, both basic and applied for actual controlled use, of radioactive materials, that is the materials which emit nuclear radiation. This was in two areas. One was their use in treatment of cancer and other ailments. The second was their use in food preservation. These fields form a part of what is generally known as 'atom for peace', in addition to electricity production. The use of radioactive material in various applications, set in motion by Dr. Bhabha, has now been well developed by Bhabha Atomic Research Centre.

Bhabha then took actions to have collaboration agreement with Canada for developing reactors based on Natural Uranium for electricity production. India had the first reactor at Kota in Rajasthan, developed under the collaboration. Further reactors were subsequently built on our own, making a range of improvements in the design, increasing the power production capacity more than three times. Today, in all there are twenty reactors of this type in India.

Other areas of Science and Technology

Bhabha had a larger vision of scientific development of India. In addition to nuclear sciences, it included areas which were related to nuclear sciences, in which he directly started

research in Atomic Energy Department (formally Department of Atomic Energy). He also started to support science initiatives in other areas.

One important area was *Electronics*. The subject was highly important in instrumentation to measure parameters such as temperature, pressure and in controlling nuclear reactors. He took steps to set up Electronics Corporation of India, at Hyderabad, though actual setting up happened after his death. On a wider front, he chaired Electronics Committee set by the Government, which mapped how electronics industry should progress in the country. He started the work of developing *computers* in TIFR, which resulted in development of India's first computing machine TIFRAC in 1962. BARC further developed TDC series of computers.

As early as 1944, Sir A.V. Hill had suggested that biophysics was neglected in India and Bhabha should take initiative to promote it. Following his principle, Bhabha was looking for the right person and waited till he found Obaid Siddiqui doing research in America to start work at BARC in *microbiology* in 1962.

For studying *radio-astronomy* he established a radio-telescope at Ooty, under TIFR, for which he gave the responsibility to Professor Govind Swaroop, who later was honoured with fellowship of Royal Society of London. The site selection for this was done very cleverly after a lot of physical efforts in surveying.

Bhabha himself being so good in *mathematics* that formed the solid base of his physics research, he invited top mathematicians, like D.D. Kosambi and Prof. K. Chandrashekharan, to TIFR and started School of Mathematics. He believed that mathematics provided the most powerful vehicle for the exact transcription of thought which could not be expressed in words.

Dr. Vikram Sarabhai was another great visionary scientist of India, who had to return from Cambridge in the heat of World War II. He continued his research at Bengaluru under guidance of Sir C.V. Raman, till he could go back to Cambridge in 1945 to complete his Ph.D. During the years 1939 to 1945, Bhabha and Sarabhai were in close contact in Bengaluru and respected each other.

After launch of Sputnik satellite by Russia, both Bhabha and Sarabhai thought it necessary that India should step into the field immediately. Bhabha convinced Pandit Nehru, who agreed to start the research in *Space Science* under the Atomic Energy Department in 1961. Sarabhai had already initiated research study of space science at Physical Research Laboratory, PRL for short, in Ahmedabad. In fact, PRL is to space sciences, what TIFR is to nuclear sciences. Bhabha set up Indian National Committee for Space Research,with Dr. Sarabhai as the obvious choice for Chairmanship and for leading the programme.

As it used to happen in other cases, the space centre started in a temporary place, a Catholic church at Thumba in Kerala, with laboratory in a cowshed and workshop in the bishop's house. Bhabha had ambitious programme in mind for the Space Research. But due to his accidental death in 1966, the responsibility of both atomic energy and space programmes was fully taken over by Dr. Sarabhai. Dr. Sarabhai is known as the father of space programme in India. Unfortunately, he too did not live long,but had set the ball rolling well before his departure.

Sarabhai was Chairman of Atomic Energy Commission for five years after Bhabha's death. He maintained the same fast tempo of work that Bhabha had set. It is to his credit that, during the short period, he started several separate organizations under 'Atomic Energy' umbrella; They include Uranium Corporation of India at Jaduguda, for uranium mining;

Electronics Corporation of India at Hyderabad, for Production of electronic and computer systems; Variable Energy Cyclotron at Kolkata, for research in particle accelerator; Heavy Water Board at Mumbai, for production of Heavy Water; Reactor Research Centre, later renamed as Indira Gandhi Centre for Atomic Research, for research in second stage reactors. He also initiated *Laser technology* programme by inviting Dr. Bhavalkar from America.

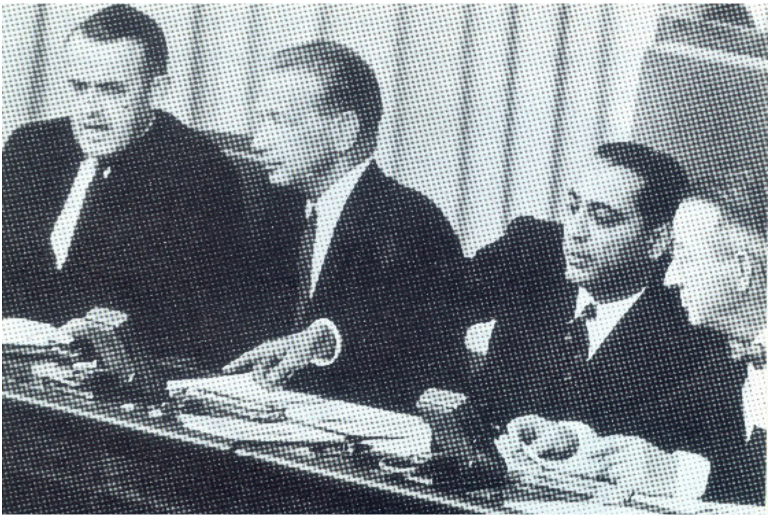
6

Bhabha on the International Scene

The discovery of nuclear energy by splitting certain atoms into fragment was made in 1939. The amount of energy was seen to be very large. Just as it can be used to generate electricity, it could be used, on its negative side, to make atom bomb. In the second world war, two atom bombs were dropped by America on Japanese cities of Hiroshima and Nagasaki. Entire world first became aware of the disastrous face of nuclear energy, before the first nuclear reactor produced electricity.

In 1953, Dwight Eisenhower took over as the President of United States of America. He asked United Nations to organize an international conference on Peaceful Uses of atomic Energy. United Nations is the global organization of the nations, aimed to help peaceful coexistence of all the nations. It has, today, 193 nations as members. In the language of United Nations, a member is called a 'member state'. It was decided to hold the conference suggested by President Eisenhower in 1955. This was the first conference of United Nations on a subject related to science and technology.

Bhabha was the person who had already started building the atomic energy programme in India, that was meant for peaceful



Bhabha Presiding over Geneva UN Conference 1955

uses of atomic energy. Entire world recognized Bhabha's efforts and elected him as the President of the conference. The speech he delivered as the President is remembered even today. He elaborated how history of man showed how man had tried to generate energy in various forms and how energy had helped man to make progress. He stressed importance of using atomic energy for production of electricity. The present technology of nuclear energy is based on splitting of heavy atoms. There is another possibility of fusing very light atoms, like hydrogen, to produce energy. But research on this way of energy generation is still in nascent stage. But Bhabha was very optimistic about it. He said that as and when fusion energy was realized, it would solve man's problem of electrical energy forever.

Setting up the International Agency

In the conference on peaceful uses of atomic energy held in 1955, it was decided to form a new international organization under United Nations, to promote peaceful uses of atomic

energy and to prevent its disastrous uses. Bhabha took very active part in forming the organization. The organization, named, International Atomic Energy Agency, IAEA for short, came into being in 1959. Under Bhabha's leadership, India had built the reactor Apsara on its own. As a result, Bhabha and Indian Scientists had gained a lot of respect worldwide. Bhabha and his colleagues participated actively in several committees of IAEA. Bhabha was also one of the Governors of the IAEA, till he was alive. He was known among the fellow Governors, and others working with IAEA, as a 'forceful and gifted' person.

Right from the days Bhabha was taking leading role in IAEA till today, India has always actively participated in all the activities of IAEA. Indians have been working effectively in IAEA offices. Indian scientists have presented valuable papers in all the conferences of IAEA. They have put up their stalls in all the exhibitions on 'peaceful uses of atomic energy'. They have collaborated with many countries for exchange of scientific matter, training, consultancy. India has helped many developing countries into peaceful uses of Atomic Energy. This is all going on the guidelines laid by Dr. Bhabha during the initial years of IAEA.

As we have seen Bhabha had a very close network of friends among leading scientists of the world. He wisely utilized the network for India to have quick entry and stability in the nuclear field. With his personal friendship with Nobel Laureate Joliot Curie, he managed to have scientists in India to spend several months in laboratories of French Atomic Energy Commission,where they could learn and absorb the new science fast. With his friendship with Bennet Lewis of Atomic Energy Canada, he succeeded in having a large team of Indian Scientists to get trained in the type of nuclear reactors India was to develop. One can understand how important is such development of expertise to start and continue atomic energy programme.

7

Bhabha - The Person

Homi Bhabha is the internationally acclaimed person, acknowledged as the founder and prime architect on Indian Atomic Energy Programme. The programme, as we see today, owes its success largely to the bold initiatives taken by this great visionary in early days. Bhabha applied all his acumen to set the ball rolling, when he established the Tata Institute of Fundamental Research as the research institute in nuclear sciences. It was the year 1944 when he took the initiative. What was the environment in the country that time?

World was yet to come to know about the enormous potential of the newly found nuclear energy. India’s freedom from colonial rule and the freedom to take own decisions was still a few years away. The subject of atomic energy was completely absent from science curricula in Universities. There was no human resource ready to take up the job. Building of expert human resource was required to be started from the scratch. Physics research in the country was nowhere near the level Bhabha had witnessed at Cambridge. Scientific persons in India of any worth were scattered. Indian industry had hardly any presence as required for implementing the programme. There was hardly any technology based industry, but for Tata

Steel Company at Jamshedpur and a few hydroelectric power stations on river dams, which generated electricity from the energy of water running down the hills.

In such a situation, where there was shortage of each and every resource, how could Bhabha get the inspiration and confidence to take up the huge challenge of building large and long term atomic programme? First, it was his upbringing in the illustrious family, that imbibed in him many positive virtues. Later in his life he had the exposure to the charged research environment at Cambridge. The decades of 1920 and 1930 were part of the revolutionary discoveries made in physical and other sciences. It was in this period, when mankind gained the knowledge of the minute levels of matter and came to know about atom, its structure, about tiny particles that made up the atom, their masses and energies. At Cambridge, Bhabha was a direct first hand witness to this unfolding story of science. He came in contact and made friendly acquaintances with great personalities in science. The interactions widened Bhabha's vision to make it more liberal.

At the same time Europe was experiencing tyranny unleashed by the German dictator Hitler. As a reaction, Bhabha developed affinity to socialist approaches. They blended with the liberal thinking he had acquired from his upbringing. All these strong factors must have made lasting impressions on the person, who was gifted with great natural talent. They made him a constructively minded, patriotic, liberal yet emphatic person with socialistic inclination. A little contrasting virtues as they may sound, their blend is what made him a unique personality.

That Bhabha returned to India was a boon for Indian science, although world might have lost the rise of a great physicist. It is to his credit that he made use of his personal virtues and capabilities constructively, in the nation building

tasks of independent India. A lesser person, perhaps, might have either wasted the opportunities or would have found excuses to remain inactive.

During the years after his return from Cambridge, Bhabha set the aim of his life – scientific progress of independent India. He founded Atomic Energy Institutes on sound foundation. Later Dr. Vikram Sarabhai was another visionary who laid the foundation of Space research. Atomic Energy Department and Space Department, formally known as Department of Space, and well known as ISRO, had so rich a guidance from the two great personalities, that scientists there remain grateful to them even today. With the strong foundation on which Atomic Energy Institutes are built, they stand out among the scientific institutes in the country.

When at Cambridge, Bhabha had expressed that he had no desire to be a successful man or the head of a big firm. But during the period 1940-45, he learnt about his own country in depth. When there were signs of the dream of country's freedom coming true, the clear picture of path to be taken by scientific progress of the country started emerging in his mind.

All round thinking of Bhabha

During the years before independence, Bhabha paid attention to all the aspects of the scientific progress of the country. He founded Tata Institute of Fundamental Research for fundamental science. He brought several institutes of Science and Mathematics under the wings of Atomic Energy Department, as Aided Institutes by providing them with funds and encouraging scientific exchanges. He started Board of Research in Nuclear Sciences to fund and promote research in Universities and Academic Institutes. He established close relationship of Atomic Energy Department with academic institutes. He started training

school in BARC to provide a continuous flow of trained human resource for atomic programme.

In developing nuclear science, Bhabha used pragmatic blend of foreign collaboration with indigenous development. In his judgement, Bhabha considered desirable and essential to enter into collaboration agreements with advanced countries, to help accelerate the efforts in India. He used to say that foreign collaboration worked like a booster. The booster assisted an aircraft to take off, but,was incapable of independent flight. It is our own science and technology would finally power the flight, the way the engine of the aircraft does. He was very particular in this respect, that whenever a foreign collaboration is made, our scientists must learn the technology and become self reliant thereon.

He started Atomic Energy Establishment, Trombay. The institute was named 'Bhabha Atomic Research Centre' after his death. This type of research institute carries out research that would have direct practical use, rather than open ended research, as done in fundamental research. It also includes engineering and technology development.

Development of industry for production of material and equipment is another important aspect of scientific progress. Bhabha emphasized building the atomic energy programme on indigenous capabilities and hence, was keen that design of the system be within the capacity of Indian industry. This automatically resulted in the capacity building of Indian industry.

One can easily see a great institution builder in Homi Bhabha. He firmly believed that, creating institutes first and then filling the posts of scientists to lead the work, was not the proper way for scientific institutes, because it would most likely put wrong persons in wrong slots. He used to say that a

large number second rate workers could not make up for a few outstanding ones. He followed this principle while setting up institutes or subject groups within the institutions.

He understood well that science development needed significant funds, which were possible mainly from Governments, especially in a developing nation. However, this may bring unnecessary controls that would prove counterproductive. With the trust between him and Pandit Nehru, he could manage to get funds and other support from the Government, yet achieving flexibility in rules of implementation.

He obtained authority for Atomic Energy Department to have own independent systems to carry out certain key jobs, such as, construction of buildings, purchases and,the most important of all, recruitment of personnel. He could get the Headquarters of the Department of Atomic Energy to be located at Mumbai, so that himself and other scientists required at the Headquarters stay near the centre of scientific activity.

The flexibility given to the Department of Atomic Energy has played a major role in speedy and quality implementation of its programmes. This is because, as Sir John Colville's said in his inaugural speech of TIFR, "great wealth, wisely husbanded and applied, individual initiative and government support are all blended in this institute".

The artist in Homi Bhabha

In addition to his zeal for advanced science, Bhabha paid attention to all aspects of aesthetic design, in implementation of the programme in the different parts of the country. TIFR is a magnificent edifice – surrounded by beautiful lawns and gardens – that stands out as a thing of great beauty, at the Land's End, in Mumbai, facing the Arabian sea. BARC site at

Sketches drawn by Bhabha-
Sir C.V.Raman and Artist M.F.Hussain

Trombay had its natural beauty, boosted expressively by the artist in Bhabha.

Bhabha had a number of traits. He was lover of music, Western, Hindustani and Carnatic, and had especially deep understanding of Western Music. He was very good at painting. He drew sketches of many of the scientists he met. Owing to his appreciation of the great artist of India, M.F. Hussain, he commissioned him to paint a large mural in the lobby of TIFR. Architectures of buildings are also expression of creativity. Bhabha had as much architect in him, as he was a scientist. He showed the creativity while creating buildings and campuses of TIFR and BARC, that blended beautifully with the natural surrounding and contours.

His brother, Jamshed, described Homi Bhabha's passion for arts aptly, "For Homi, the Arts were not just a form of recreation or pleasant relaxation; they were most serious

pursuits of life. For him, the arts were, in his words, 'what made life worth living'."

In the words of the British Nobel Laureate Sir John Cockcroft, "Human Progress has always depended on achievements of a few individuals of outstanding ability and creativeness. Homi Bhabha was one of them." Bhabha was a visionary person with boldness and conviction about what he was doing. He had relentless energy and drive to convert his vision into reality. He drove himself no end to give his maximum to science and to the country.

On January 24, 1966, while on his way to Vienna to attend a meeting of Scientific Advisory Committee of International Atomic Energy Agency, Bhabha was killed in an air crash on the Mont Blanc in the Alps. India lost an outstanding scientist, a brilliant engineer, a great lover of music, a gifted artist, a patriot and, in the words of Nobel Laureate Sir C.V. Raman, "the modern equivalent of Leonardo da Vinci". Truly, like the great Italian Leonardo da Vinci, Homi Bhabha was a person of great learning in several fields of study. Usually, when a leading personality passes away, public establishments are closed as a mark of respect. When Bhabha died, all the institutes of Atomic Energy Department in India observed a working day.

8

Bhabha - the physicist

Physics research at Cambridge

At Cambridge University, Homi Bhabha first passed out his Tripos in Mechanical Engineering, and subsequently also in Mathematics. He was highly impressed by the research ambience at Cambridge. The top scientists working there included Ernest Rutherford, Paul Dirac, James Chadwick. In theoretical physics, quantum mechanics was fast developing. In the experimental physics, discoveries in nuclear and atomic structure of matter were being made. It was a period when revolutionary research work was seen to take place in atomic physics. Bhabha registered himself for Ph.D. in physics at Cambridge. His research in Cosmic Shower of protons, electrons, positrons and other particles, earned him his Ph.D. Doctorate in 1933.

He utilized the scholarship he received in Mathematics for travelling to meet and work with leading scientists in Europe, like Niels Bohr, Wolfgang Pauli, Enrico Fermi. He received 'Isaac Newton Fellowship' in 1934, with which he could continue his research work in Physics at Cambridge. He then received '1851 Exhibition Scholarship' in 1937, with which he could further continue his research in physics. Thus, Dr. Homi Bhabha could carry out his research work in physics at Cambridge between

1932 and 1939, that is, for a period of seven years. His main topic of research was in the field of Cosmic Rays.

Bhabha's Research on Cosmic Rays

Cosmic rays are the particles that bombard the earth's atmosphere, like rain shower, from anywhere beyond earth's atmosphere. They consist mostly of nuclei of hydrogen and helium, and of 'beta particles', which is the name given to high energy electrons emitted by nuclei of atoms. During his Ph.D. studies, Bhabha's research was about absorption of cosmic rays by matter.

Bhabha Scattering

Later he studied electron-positron scattering. Positrons are particles equal in mass with electron, but having positive charge, equal in amount to that of electron. Electron-positron pair is generated from certain nuclei after collisions by high energy particles. Bhabha's research dealt with the way positrons are scattered by electrons. In 1935, Bhabha published his work on calculations of Electron-Positron scattering. In honour of his contribution, this work got known as 'Bhabha Scattering'. Bhabha Scattering subsequently resulted in wide scale worldwide research on the subject, and in production of thousands of research papers by many scientists.

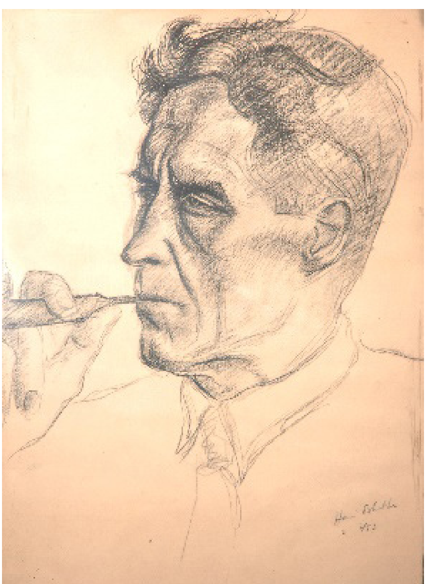
Cosmic Shower

In 1936, he visited the Wills Physical Laboratory at Bristol and worked with a senior scientist, Walter Heitler. With Heitler, Bhabha developed the now-famous Bhabha-Heitler cascade

theory. The theory introduced for the first time the concept of 'cosmic air shower'. It showed that when cosmic rays hit earth's atmosphere, they produce, through their interaction with atmosphere, secondary particles, in a sequence. It is because of the occurrence of the sequence that it is called 'cascading effect'. This effect causes a shower of particles, like a rain shower. It is known as 'cosmic shower'.

Mesons

He, then, turned his attention to other aspects of cosmic rays. He predicted that there were some cosmic rays which were highly penetrating and that they consisted sub-atomic particles, which are about hundred times heavier than electrons. His last research paper in this subject was on theory of the sub-atomic particles called 'mesons'. Mesons are particles similar to those he had predicted to be present in cosmic rays. Later, cosmic rays were indeed seen to contain mesons! Interestingly, the name 'meson' was coined by Bhabha and was accepted by all.



Sketch of Professor P.M.S. Blackett drawn by Homi Bhabha

All radioactive elements and particles disintegrate by emitting radiation. Disintegration of every particle follows a certain time pattern. Bhabha predicted that, when meson is moving with very high velocity,

its time of disintegration would expand, in accordance with Einstein's theory of relativity. This was experimentally verified later.

Bhabha was, thus, deeply involved in research in atomic particles. He continued his valuable research work at Cambridge till 1939. His achievements have earned Homi Bhabha a permanent place in physics text books on cosmic rays.

Bhabha received in 1939 the Royal Society grant to work at Manchester in the laboratory of the Professor P. M. S. Blackett. But, while he was on a vacation in India, World War II broke and Bhabha could not return to Cambridge. He then continued his research in India.

Bhabha's Physics Research in India

Bhabha had a lot of unfinished research work at Cambridge. That was more mathematical in nature. Bhabha joined Indian Institute of Science in Bengaluru and continued his research in cosmic rays there.

Rising above the difficulties

Bengaluru is close to geomagnetic equator. It was one of the few places in the world that time where it was possible to study cosmic rays near equator. It was seen by scientists that intensity of cosmic rays was consistently lower near equator. Experiments showed later that low energy cosmic rays were almost absent near geomagnetic equator. This makes it a better place to study high energy cosmic rays. In India, the geomagnetic equator passes near Thiruvanathapuram, in Kerala. Bhabha took this opportunity to continue his cosmic ray research in Bengaluru, which was not far from the geomagnetic equator.

However, adequate facilities for the experiments were lacking. Experts in Electronics and Instrumentation were not easy to get in India of those days. As the resourceful person that Bhabha was, he overcame all the difficulties. He managed to get some electronics personnel for building two types of telescopes, called 'Geiger Counter Telescope' and 'Geiger Muller Telescope', in the country. They are, in fact, Particle Telescopes, which detect high energy sub-atomic particles coming from Space. He also managed to send these telescopes on aircrafts of U.S. Air Force stationed at Bengaluru. The measurements Bhabha made in this way were the first measurements intensity of atomic particles, named 'mesons', obtained at high-altitude near equatorial latitude.

The Experiments Bhabha missed in England

Bhabha, then, built the equipment called 'Circular Cloud Chamber',. The same equipment was also being built at Manchester by P. M. S. Blackett, where Bhabha had planned to do his research. Had Bhabha not been stuck in India after his return in 1939, he would have been a part of the experiments at Manchester. The world war had created obstacles in his plan. But, Bhabha had converted his difficulties into advantage, by building the necessary equipment in India and hiring U.S. Aircrafts for conducting the experiment. The funds for the projects were supplied through a grant from Sir Dorabji Tata Trust.

It was unusual for a theoretical physicist like Bhabha, to work closely into experimental physics. Theoretical physicists make more use on mathematical analysis, while experimental physicists base their study mainly on conducting experiments. But as the situation demanded that Bhabha, though basically a theoretical physicist, should conduct experiments. He did not

give up. He carried out the dual role, a role in both theory and experiment. This speaks highly of his genius and dedication.

While at Cambridge, Bhabha was impressed with the thoughts expressed by Physicist J.D. Bernal, a crystallographer. Bernal used to say that Science, which was bringing about change in the society, was not an abstract work. He believed that Science had its firm roots in society and its benefits, therefore, should reach entire society, and not just be limited to rulers. After returning to India and watching social and political environment in the country, Bhabha's thoughts started encompassing wider domain, rather than just being satisfied with physics. He started thinking about scientific progress of India, especially after possibly forthcoming independence.

During that period, that is, the first half of the decade of 1940s, dramatic events were taking place on the world stage in nuclear physics. . The field of nuclear physics had taken a new turn after discovery of nuclear energy that can be tapped for human use. Bhabha was keeping track of these developments and thought that it was high time India entered the field.

9

Discovery of Nuclear Energy and Activities in India

While at Cambridge, Bhabha had developed warm relationships with several top scientists who were engaged in the research in the field of atomic physics. Rutherford, who worked at Cambridge, had developed atomic model showing a central nucleus around which a cloud of electrons existed. Niels Bohr, who worked at Copenhagen in Denmark, improved the Rutherford Model further by discovering that electrons around the nucleus revolved in certain defined orbits. These discoveries took place in the decade of 1910. James Chadwick discovered neutrons in 1931. Neutrons have no electric charge. Hence, they had defied any detection so far. Discovery of presence of neutrons in nucleus, along with protons, in a nucleus solved many puzzles at that time.

Bhabha himself was a particle physicist, that is, a physicist studying particles in atoms. 'Cosmic Rays', which was the research topic of Bhabha, also was an important subject in the domain. Cosmic rays are high energy radiation coming from outer space, mainly outside solar system. They provided a natural laboratory in atmosphere and space, for study of high energy atomic particles. Bhabha was, thus, very closely

connected with scientific developments in nuclear physics. But it was only after he returned to India that the phenomenon of release of nuclear energy was discovered.

Experiments with neutrons

If a neutron emits an electron, it will turn into a proton. If any neutron in the nucleus of an element turns into proton, atomic number of the element will increase by one, creating a different element of chemical periodic table. Enrico Fermi thought that this was what must have happened, when he conducted experiment by bombarding atomic nuclei by neutrons. He concluded that new elements of higher atomic number were formed by bombardment of uranium nucleus by neutrons. Later on Otto Han from Germany proved it to be a different process.

Otto Hann also conducted experiments similar to those conducted by Enrico Fermi. Being a chemist, he could detect presence of barium after bombarding uranium nuclei by neutrons. After a lot of thinking and discussions, he concluded in 1939 that uranium nucleus, in fact, splits into fragments after neutron bombardment, releasing high amount of energy. Otto Hann received Nobel Award for his discovery in 1944.

What was done with atoms releasing energy

Enrico Fermi, who had shifted to United States of America, took up the research on the nuclear energy further. He developed an experiment, where he could get uranium atoms bombarded by neutrons continuously, in a controlled, self-sustained manner. He was, thus, able to have sustained nuclear chain reaction, which could generate continuous and steady flow of energy in the form of heat. The experiment created

possibility of building a nuclear reactor generating heat energy which could be converted into electrical energy by well known methods. It took several years for Fermi to erect the first nuclear reactor. The first nuclear reactor to produce electrical energy was completed only in 1951.

The dark side was shown first

The period between discovering nuclear energy in laboratory and building the first nuclear reactor was also the period when World War II was being fought vigorously. Many scientists were diverted to research on making nuclear bomb, also known as atom bomb, using the tremendous energy released in the nuclear reaction. Two nuclear bombs were actually dropped in 1945 from the war planes, on Hiroshima and Nagasaki in Japan, during the World War II. Huge loss of human life, health and property was caused by these tragic events. Nuclear Weapon, thus, was made by mankind much before electricity could be generated from nuclear reaction.

But the bright side did emerge

The constructive minds of scientists kept on taking the research forward for using the nuclear energy for human good. They pursued two aspects of nucleus in that direction. The first was generating electricity by controlling the nuclear chain reaction. The first reactors, built in America, England, Canada, France, Russia, were made to gain sufficient knowledge and experience in making the nuclear reactor. Then followed the step of making larger reactors for electricity production.

There was another aspect of nucleus which could be put to use. Many elements are radioactive. That means their nucleus emits certain radiations, either in the form of tiny sub-atomic

particles, or in the form of electromagnetic waves, called gamma rays. Such elements are present in nature also. We do receive radiations from outer space, from earth, from food we eat, from air we breathe. But that is very miniscule in quantity. If the radiation is too strong, it is harmful to all living beings. But, in controlled small quantity the radioactive substances can be used to treat many ailments like cancer, in medical diagnosis. It finds uses in agriculture and industry too. It is this useful aspect of nucleus which attracted the scientists to go further.

These two aspects, namely, electricity production, and good use of radioactivity, are known and promoted as 'atom for peace'.

Bhabha becomes the Torch bearer in India

Dr. Homi Bhabha, who was carrying out research in cosmic rays, was keeping track of developments in the field of nuclear physics. His interest, of course, was in 'atom for peace', that is, the constructive aspects of nuclear energy. He was looking at nuclear energy for producing electricity. He was watching the developments in this field taking place world over. The entire international circle of scientists, who were engaged in nuclear energy research for production of electricity were well known to Dr. Bhabha.

Laying foundation for nuclear science in India

Bhabha started with establishing an institute for research in areas which would be of use in developing atomic physics and related field. On 19th December 1945, the institute, named as 'Tata Institute of Fundamental Research', TIFR for short, was inaugurated. The research at TIFR started in Theoretical Physics, Nuclear Physics, Cosmic Rays, Mathematics, Chemistry and Computers.

Particle accelerator is another important area in which Bhabha started the work as soon he started the institute. Particle accelerator is an equipment, which can impart huge amount of energy to tiny atomic and subatomic particles, such a protons, electrons, ionised particles. This enables study of behaviour of the particles at very high speeds and energies in laboratory experiments. Bhabha attempted to import one accelerator from America. But America refused to give it to TIFR. He then initiated work to develop one at TIFR. A small accelerator was made in 1950, but could be put into operation. It was only in the decade of 1960s, that India got its first particle accelerator. Later, several particle accelerators were built by Indian Scientists.

Putting atoms to work

TIFR was established to carry out fundamental research. This type of research is done to make discoveries in basic sciences. It helps in laying the foundation on which useful systems could be built. On the other hand, research institutes that carry out research in applied areas are established with the purpose of building up new equipment and systems for meeting certain objective. Bhabha started taking actions for setting up institute for applied research in nuclear science, engineering and technology, for peaceful uses of atomic energy. This had two aspects, electricity production and use of radioactive material in medicine, agriculture and industry.

For carrying out all the work in the field of atomic field, Atomic Energy Commission was set up by Government of India in August 1948. It is the highest body in the country responsible for managing everything related to nuclear field, from making policies to implementing projects. Actual implementation is done by Department of Atomic Energy which works under the commission. The department was established in 1954. All the

powers of Government of India in nuclear domain rest with Atomic Energy Commission. Bhabha was the natural choice to be Chairperson of the commission. He continued to hold this post till his accidental death in 1966.

10

Everything You Need to Undertake The Nuclear Programme

Bhabha had clear vision of what all would be required to succeed in the nuclear programme without leaving any gaps. He was fully aware about capabilities and expertise available within the country. He knew where country would need scientific and technical help from other countries, which were ahead in nuclear field. He was knowledgeable about status of science and various technologies in the world. He also kept himself informed about intelligent Indian personnel having expertise in related fields and working in laboratories, both within and outside India. He was eyeing on them to bring them back to India if they were abroad and getting them to lead nuclear research in India.

With his all round knowledge of the subject, Bhabha prepared a short note, of 2-3 pages, for the Prime Minister Nehru in 1954, listing all that was necessary to undertake the national nuclear programme. The note was complete in itself. It was so thoughtfully made that, even after 60 years, we find that India's nuclear programme was moving more or less on the same lines as given in the note. The remarkable point about

the note was that it was prepared years before any commercial nuclear power station was in regular operation anywhere in the world. That speaks volumes about vision, foresight and confidence of the man.

Two important enablers – man and material

Of all the tasks required to make progress in the nuclear programme, two were required to be taken up with the highest priority, which he did. It the nuclear and radioactive substances that make the work in atomic and nuclear fields so very different from other fields of science and technology. Therefore, the first job to be taken up immediately after independence was the control, management and processing of the materials, which were crucial from the point of programme. Second important work, which needs time to get fully set up and which is required all the time in future, is development of human resources. It was necessary to set up a system to generate sufficient number of experts continuously. Bhabha wasted no time in starting these two activities.

Front end of fuel cycle: Three steps to get hold of nuclear fuel

There are three steps of the work related to materials till it gets ready as a fuel for nuclear reactors.

The first step is the system to survey all the areas in the country and to locate natural deposits of minerals, which would be useful for the nuclear programme. For generating nuclear power, we have to locate natural deposits of Uranium and other important substances like beryllium, zirconium etc. For exploring India's vast land for minerals, Bhabha set up the Atomic Minerals Division very early in the programme.

It started surveying large areas of the country. In 1951, large deposits of Uranium were located at Jaduguda in Singbhum area, which now in Jharkhand. It became the main source of Uranium for the country and the supply continues even today.

The second step pertains to mining of the minerals and extracting the required chemical compound out of them. Minerals are naturally occurring solids in earth structure, including earth surface. Uranium minerals at Jaduguda are contained in the rocks about 600 to 900 meters below earth's surface. We have to extract out of that the part containing the required substance in sufficient concentration. This concentrated part is called 'ore'. We need to process the ore further to get the required compound. This compound is Uranium Oxide in the form of powder, which is traditionally called 'yellow cake', although it is actually not in the form of a cake. Work of setting up Uranium Mill at Jaduguda was taken up by Bhabha immediately.

Sands in Kerala contain large quantities of the mineral called 'Monazite'. It contains Thorium and Uranium, which are useful for making fuels. Uranium itself is a fuel, while Uranium can be bred from Thorium, in nuclear reactors themselves. The monazite sands also contain many other chemical elements very useful in nuclear field. Bhabha was fully aware of the significance of sands of Kerala coast, and also of the entire eastern coast of Tamil Nadu and Orissa. He set up units in Kerala for extracting Thorium-Uranium ores and extracting other materials. He did this in the decade of 1950 itself, even before any activity started at Trombay.

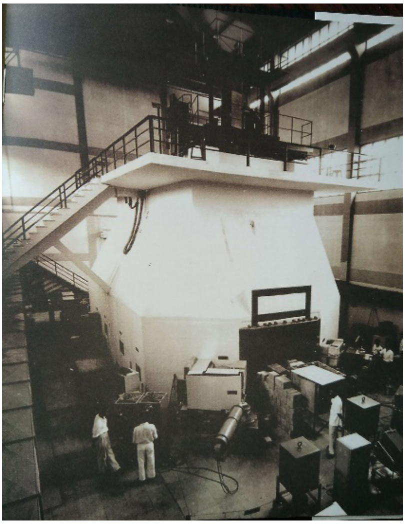
The third step is to process the 'yellow cake' to make Uranium Fuel Pellets and enclose them into metallic tubes. These tubes are, then, made into fuel bundles, which can be used in the nuclear reactors. In the decade of 1950, Bhabha set uranium and thorium plants at Trombay in Mumbai. He got some Uranium

as a by product of Copper Mine Units in Jaduguda. He also set up Fuel Fabrication Facility to make fuel bundles to be loaded into reactors. Chemistry Division of TIFR, and later Chemistry Division at Trombay, developed technologies for obtaining Uranium. Later, in 1969 a separate organization, named 'Nuclear Fuel Complex', was set up at Hyderabad for manufacturing reactor fuels.

You can see how, in the decade of 1950 itself, Dr. Bhabha set up entire fuel chain from Uranium mining to fabricated fuel ready to be loaded into reactors. This chain is called 'Front End of Fuel Cycle'.

Developing the most important asset - people

The second task taken up on priority was developing expertise in all the areas of nuclear field. As this was to be done as a long term process, it was important to establish a stable system to do it. Bhabha had invited eminent scientists to join TIFR, many of whom had joined. He set up laboratories around each of them, where they started research in their own areas relevant to Nuclear field. This prepared the first front of experts. In 1954, laboratories started getting set up at Trombay. The same TIFR experts started setting up scientists' groups in several subjects at Trombay, where hands on experience was given high importance. This prepared the next front of experts.



Beautifully shaped Apsara Reactor

In 1954 Bhabha had taken a bold decision to set up one small nuclear reactor indigenously at Trombay. He wanted the scientists to have the first hand experience in building a nuclear reactor. He was confident that it was the best way of learning. He selected 'Swimming Pool' type of reactor to be designed, because the scientists in Trombay at that time had the confidence of building this type of reactor. It was also possible to manufacture necessary components of such a reactor by Indian Industry. The only part that India did not have facility to make, were the special fuel rods, containing enriched, meaning purified, uranium. The fuel rods were imported from United Kingdom.

The work of building the reactor started in 1955 and was completed very fast. It produced thermal power equal to 1 megawatt. The reactor became operational in January 1957. Prime Minister Pandit Jawaharlal Nehru formally inaugurated it on 20th January 1957. Looking from the top into the pool of the reactor, one could see beautiful blue radiation called 'Cerenkov Radiation'. The reactor was named 'Apsara'. On the same day the Prime Minister formally inaugurated 'Atomic Energy Establishment, Trombay', AEET for short, as the institute to spearhead the nuclear programme of India. The institute, now known as 'Bhabha Atomic Research Centre', is the mother institute of all other institutes under Atomic Energy Department.

Apsara was a research reactor. It did not produce electricity. Building the Apsara reactor on their own has been very useful for the scientists from the point of view of building expertise in the atomic subjects. It gave valuable experience in nuclear reactors. It also provided facility for producing new varieties of some of atoms, called isotopes of the atoms. All isotopes of an element have same number of protons but different number of neutrons. If an isotope is radioactive, it is called radioisotope. They are useful in many areas, such as medical field, agricultural field, industry etc. Apsara also provided a laboratory for nuclear

physicists to perform new experiments. The reactor was in operation till the year 2010.

Setting up the Training School

In addition to building own reactor, a great step was taken by Dr. Bhabha to start the AEET Training School, which provided training facility for new scientists joining AEET. The scheme worked out for running of the training school has been very fruitful and successful in the last 60 years. In the first several years, scientists present at the centre and some experts from outside started teaching at the training school. The students joining the training school were those who were already selected for joining as the scientists at AEET. The selection was done through a very tough interview, testing only the understanding of the student in fundamentals of his subject and his aptitude to do research work. After successful completion of the training, the students join the laboratory of his subject, gains experience in research and, if he is good at teaching, starts teaching new entrants in the training school. It, thus, becomes a self-sustaining scheme. This scheme, started in 1957, is continuing till today, and has provided very able researchers to the nuclear programme of the country.

Building nuclear reactors

The two tasks, namely, getting fuel ready for loading into reactors and creating trained human resource, were primarily aimed at building India's own nuclear reactors. It was preferable that the nuclear reactors to be built by India should use the fuel available abundantly within the country. India has limited deposits of Uranium in its earth structure, but has large deposits of Thorium. Realizing this fact, Bhabha designed a three stage

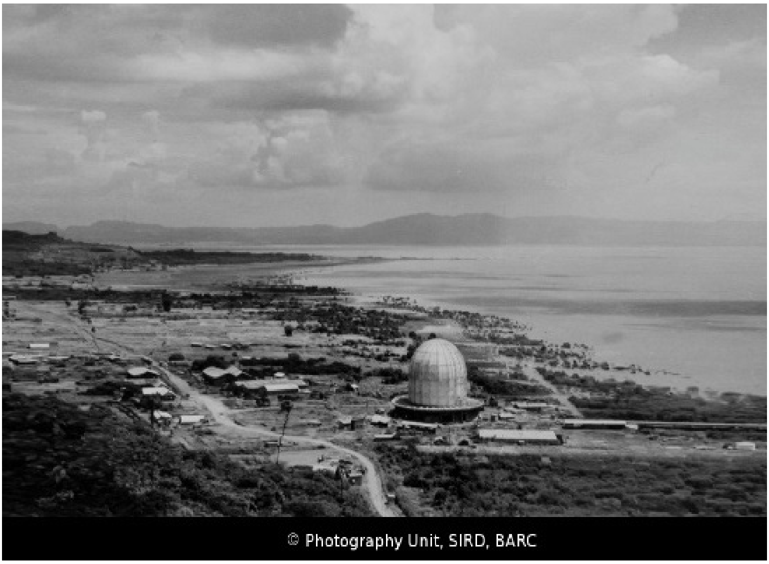
programme, specific to India, for building nuclear power stations for generating electricity, based on the availability of fuel material in India.

The nuclear programme designed by Bhabha was based on Uranium in the first stage. In the second stage, the artificially made fuel 'Plutonium' was to be used, while Uranium made from Thorium was to be used in the third stage. In the first stage, his programme was designed to use the Uranium in its natural composition, because it needed minimum processing of the ore. These types of reactors were being designed in Canada. But, their final design to generate electricity was still getting ready in the decade of 1950s.

Bhabha did not want just to keep waiting till the Canadian technology got fully ready. He, therefore, adopted a two way path to get ready for the first stage. He decided to purchase two reactors from America. Although, these type of reactors did not fit into his three stage programme, their design was ready for construction. The purpose of getting those reactors was to get first hand experience of constructing nuclear power stations. The experience included all the aspects of erecting nuclear reactors, producing electricity and supplying it to the country's electrical power grid. This was the first path on which nuclear programme of the country was activated.

Collaboration with Canada

On a parallel path, he entered into an agreement with Canadians for development of a research reactor at Trombay. It was the agreement for development and not for purchase, unlike one he had done with Americans. This was because the collaboration with Canada was for starting India's own three stage programme, which was not the case with American reactors.



CIRUS Reactor getting completed

The first reactor using natural uranium was to be based on 'NRX' reactor operating in Canada. However, there were some basic design changes required to be made. Also, Bhabha had decided that half of first lot of fuel to be loaded into the reactor would be made in India. This was a difficult task at that time. But he had so much confidence in ability of his colleagues to succeed in making the fuel, that he declared so when he visited Canada in 1956 itself. Finally, Indian scientists did succeed in making the fuel for the reactor, which proved to be of the same quality, if not better, as Canadian fuel. The reactor set up at Trombay and known that time as Canada India Reactor, was later named CIRUS. Its thermal power was 40 megawatts. Like Apsara reactor, CIRUS was also a research reactor, and provided facilities for producing isotopes and for research in nuclear physics. The reactor was in operation till the year 2010.

Heavy Water production

Indian Reactors in the first stage were required use Heavy Water as 'Moderator'. The moderator is used for doing the job of slowing down the neutrons to a lower speed, where they were the most effective in causing further nuclear reaction of splitting the atoms into fragments. It was therefore necessary to manufacture 'Heavy Water' in India.

Heavy water is a type of water, where hydrogen atom in its chemical composition, H_2O, is replaced with an isotope of Hydrogen, called Deuterium. Chemical composition of Heavy Water is D_2O. The technology for heavy water production had been a very difficult technology. Bhabha realized the necessity to start ahead of time to master the technology and to be ready by the time reactors were built. One way of manufacturing heavy water was to associate that process with manufacture of fertilizer, as its by product. That is how Bhabha started the work in 1954 itself. He erected a heavy water plant along side fertilizer plant at Nangal in Punjab. The heavy water production started there in 1962. That plant operated for nearly 40 years.

The first nuclear power station of the first stage

Then came the time of building the reactors of the first stage for producing electricity. India entered into another agreement with Canadians for building reactors based on their design of the 'Douglas Point' Reactor operating in Canada. It fitted well into the first stage of Bhabha's three stage programme. It was decided to erect four reactors of that type and producing 220 megawatts of electric power, two at Kota in Rajasthan and two at Kalpakkam in Tamil Nadu. The work started in 1964. This time, too, the agreement was for collaboration and not for purchase.

As planned by Dr. Bhabha, the progress was made in such a way that Indian scientists would fully absorb the scientific and technical knowledge of the reactors. This proved extremely thoughtful and useful later.

In 1974, citing the reason of Peaceful Nuclear Explosion test conducted by India, Canada walked away from the agreement and stopped working with Indians. This was after construction one reactor at Kota was complete and the second reactor was half way through. Because Indian scientists and engineers had full knowledge of the reactor, they not only completed the remaining three reactors, but, also, later improved the design significantly and increased power level for future reactors. India's nuclear programme is mainly based till today on this type of reactors. Four reactors of indigenous design having 700 megawatts electric power are now under construction and Government has sanctioned in 2017 ten more reactors of the same type.

It is noteworthy that the research work for the second and third stages of the programme was started by Dr. Bhabha within the first 7-8 years of the starting the work at Trombay. India is now ready with the nuclear power station of the second stage. A research reactor of the third stage also has been built.

Reprocessing of spent fuel

The nuclear fuel is loaded into reactors in the form of pellets enclosed in metal tubes, called fuel rods. The tubes are made of metals like Zirconium or Stainless Steel. After the maximum possible energy is obtained from the fuel, the fuel rods are taken out. Their temperature at that time is very high and they also are highly radioactive. They are allowed to cool for several years in a special arrangement before taking them for further processing.

Back end of fuel cycle

The fuel used in the Indian reactors of the first stage is natural uranium. It contains less than 1% of uranium useful for producing energy. More than 99% of it is another variety of uranium which does not participate in energy production. But while remaining inside reactor, it also gets bombarded by neutrons and some part of it gets converted to Plutonium which is a fuel. Thus, the spent fuel coming out of reactors also has very useful fuel elements.

It is required to process the spent fuel in a suitable industrial plant to recover Plutonium. The processing of the fuel after burning it in the reactors is called 'reprocessing'. Bhabha had based India's nuclear programme on reprocessing the spent fuel in all the possible ways, so as to extract maximum energy out of it. After all the possible processing, the remaining portion becomes the nuclear waste. All the processing done on the fuel after it comes out of reactor is called 'Back End of Fuel Cycle'.

Bhabha took very early steps, so that Indian scientists master the reprocessing technology. Today, in the reprocessing technology, India stands equal to, or even better in some respects, than advanced countries. The remaining nuclear waste, after all useful part is taken out, is still radioactive. It is properly sealed and kept underground. After a few decades, it would be buried in the sealed form deep inside the earth.

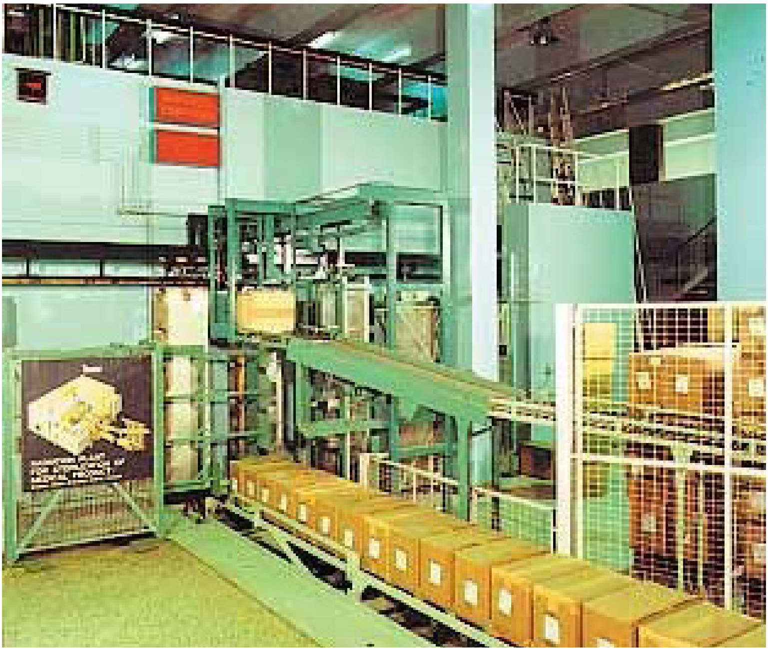
Bhabha had the full plan ready

We can see how Dr. Homi Bhabha made the all inclusive master plan for the nuclear programme of India at the very beginning itself. With his wisdom, deep knowledge of all the sciences, vision and foresight, he could draw a perfect plan which included not only scientific technical aspects, but also

development of expertise, science education, research and even boosting Indian industry to take challenges of this new field.

Uses of radioactive isotopes

In addition to use of some elements for producing energy for electricity generation, radioactive material has many other uses in medical field, in agriculture and in Industry. They form important part of uses of the 'atoms for peace'. Bhabha was very quick to initiate research work in this area. In medical field, radioactive elements are very useful in treating cancer and in thyroid related ailments. Radioactive elements also prove to be very effective in medical diagnosis. These elements of specific varieties of elements such as Cobalt, Iodine, Cesium etc. are



ISOMED Fcaility at Trombay, Mumbai

called ‘radioisotopes’, where ‘radio’ stands for radioactive and ‘isotope’ means a particular variety of the element.

Bhabha established the Radiation Medicine Centre for medical use of radioisotopes in 1963. The centre was attached to Tata Memorial Centre, which was the institute for research and medical treatment in cancer. The radioisotopes are also useful in sterilization of surgical instruments and other medical accessories. Sterilization is the process of making something free from bacteria or other living microorganisms. Dr. Bhabha initiated the work in this area in the decade of 1960, which resulted later in forming a unit named ‘ISOMED’, for sterilization of medical products.

Food preservation is another area where radioisotopes prove useful. Bhabha started work for this which has resulted into useful technologies for preserving spices, onions, mangoes, food grains etc.

11

Bhabha's Three Stage Nuclear Programme

When Dr. Homi Bhabha started designing India's long term nuclear programme, he had to base it on a strong footing. It had to be made in such a way that the programme sustains itself in a self-reliant manner, without depending much on the other countries. The most important point to be considered was the availability of nuclear material in the country.

It was estimated that Uranium would be available from Indian mines, but its quantity would be limited. If the nuclear programme is fully based on Uranium, it might last for several decades. But beyond that period, India would have to import Uranium. On the other hand, Thorium, from which we can produce a different isotope of uranium fuel, is abundantly available in the country. Therefore, eventually, India's nuclear programme has to make its way to Thorium based technology for electricity production.

Development of Thorium based technology and its use to generate electricity is the first guiding principle behind India's nuclear programme designed by Bhabha.

Once atoms of fuel material break into fragment in a nuclear reactor, many radioactive elements are generated. Radioactive elements keep on emitting nuclear radiation for a very long time. The nuclear radiation is very harmful for living beings. Although, most of the elements in the burnt fuel stop to be significantly radioactive after several months, there are some elements who continue to emit radiation upto one lakh years.

It is of utmost importance to bring the quantity of nuclear waste of burnt fuel down to minimum. It is, therefore, necessary that we should reprocess the spent fuel coming out of nuclear reactors and recycle it. It has another big advantage also. It produces artificial fuel in the form of Plutonium which can be used in another type of reactors.

This type of fuel cycle, where fuel is recycled to the maximum possible extent, is called 'Closed Fuel Cycle'.

Adopting closed fuel cycle is the second guiding principle behind India's nuclear programme designed by Bhabha.

The two guiding principles demand that we should have full knowledge in two technologies, namely, Thorium based nuclear technology and technology for reprocessing of spent fuel. The experts in nuclear science and technology must be available within the country.

Development of own human resource for becoming self reliant in nuclear technologies is the third guiding principle behind India's nuclear programme designed by Bhabha.

Based on the three guiding principles, Bhabha designed *India's Three Stage Nuclear Programme.*

In the first stage, India would have nuclear reactors which use natural uranium as fuel.

In the second stage, India would have nuclear reactors which use plutonium as fuel. The plutonium would be produced in the nuclear reactors of the first and second stage.

In the third stage, India would have nuclear reactors which use Uranium-233 as fuel. The Uranium-233 would be produced from Thorium in the nuclear reactors of the second and third stage.

Annexure I

Bhabha: A Chronology

1909	October 30, born in Mumbai (then Bombay)
1924-1927	passed Senior Cambridge at Elphinstone College and Royal Institute of Science.
1927	October, joined Gonville and Caius College, Cambridge, England
1930	Graduated in Mechanical Science Tripos
1932	Mathematics Tripos with Rouse Ball Travelling Studentship in Mathematics. Visited Copenhagen and Zurich.
1933	Received Isaac Newton Scholarship
1934	Ph.D., Cambridge
1937	Bhabha-Heitler Cascade Theory of Cosmic Ray Showers, article published in 'Proceedings of Royal Society'
1939	Stranded in India as World War II begins
1940	Special Reader in Cosmic Ray Physics, I. I. Sc. Bangalore
1941	Elected Fellow of Royal Society, London
1942	Adam's Prize, Full Professorship of Cambridge University, Cosmic Ray Research Unit, I. I. Sc. Bangalore
1945	Foundation of TIFR; Director, TIFR
1946	Member, Atomic Research Committee, CSIR
1947	Chairman, Board of Research on Atomic Energy
1948	Chairman of the newly established Atomic Energy Commission, India; Hopkins Prize of the Cambridge Philosophical Society

1954	Padmabhushan award; became Secretary to Government of India, DAE; Founding Director, Atomic Energy Establishment Trombay
1955	President, First International Conference on Peaceful Uses of Atomic Energy, Geneva
1956	Apsara swimming pool reactor operationalized
1957	Training School established at AEET; President, National Institute of Sciences, India (NISI)
1959	elected Honorary Fellow of the American Academy of Arts and Sciences; member Governing Council, IAEA
1960	CIRUS reactor operationalized
1963	Appointed Chairman, Electronics Committee; elected a foreign associate of the National Academy of Sciences of the USA
1960-63	President, International Union of Pure and Applied Physics
1965	Plutonium Plant at Trombay inaugurated; Electronics Committee Report finalized.
1966	Jan24 Death over Mont Blanc, Alps in the crash of Air India's plane 'Kanchanjunga'.

Annexure II

How Do Atoms Release Huge Amount of Energy

Why protons and neutrons stay together in the nucleus

We know that all the atoms have a nucleus at their centre and have electrons revolving around the centre in certain orbits. Nucleus consists of two types of nucleons, protons and neutrons. Protons are electrically positively charged particles and are equal in number to the number of electrons revolving round the nucleus, which are negatively charged. This makes the atom electrically neutral. A neutron has mass nearly equal to that of a proton, but has no charge.

We also know that particles with electric charge of opposite polarity attract each other, while those with the same polarity repel. There is no electrical force either of attraction or of repulsion, in case of neutral particles. How come, then, that a number of positively charged protons and neutral neutrons stick together in a nucleus and do now repel each other?

This is all because of force existing inside the nucleus, called ‘strong interaction’. It is strong enough to overcome repulsive force of electric charges of the same polarity, but only at a very small distances, less than about a femtometer, that is one-thousand-billionth of a millimeter. At distance longer than that it fast vanishes.

Just to understand this phenomenon, we may liken it to some beads sticking together with some kind of gum. At very small distances the gum makes them stick together, even if we

try to pull them apart. But once beyond certain distance, gum does not have enough strength to pull the beads back. We may also note that, to pull apart the beads sticking together with gum, we have to apply force, that means we have to supply energy. Similarly, we have to supply energy from outside when we pull apart protons or neutrons sticking together in a nucleus. Opposite of that also is true. That is, *when protons and neutrons come together to form a nucleus, they release energy. This is called binding energy.*

Mass gets converted into energy

But where does this energy come from? This comes from their mass. Some of their mass gets converted into energy. That is how the nucleons, when they come together to form a nucleus, lose some mass. This is called *'Mass Defect'*. Thus, we note that binding energy represents loss of mass in the nucleus.

Very large atoms have a large number of nucleons in their nucleus. Each one of them has some binding energy with every other nucleon. But nucleons on the outer side are a little away from many other nucleons. That is why their binding energy is low. That makes average binding energy of the nucleons in the nucleus of large atoms smaller than that of smaller atoms. That also makes them more susceptible to breaking.

When a large atom, such as that of Uranium, is bombarded with neutrons, it breaks, splits into two or three fragments. Average binding energy of all the smaller fragments is more than that of original Uranium atom. More binding energy means more loss of mass. Thus, we conclude that after splitting, total mass of the fragments is less than the mass of original Uranium atom. This lost mass gets converted into energy and is available to us in the form of heat.

The process of splitting of large atoms into smaller fragments is called 'Fission'. This is what is done in nuclear reactors to produce energy.

The element, atoms of which can split into fragments and generate energy, is called 'Fissile Material'.

The quantity of the energy generated by nuclear fission is very huge. For the sake of comparison, the calculation shows, that the amount of energy produced if all the atoms in one gram of pure fissile Uranium split, is the same as that we get by burning fully 2000 Kilograms of Petrol. In practice, fuels never burn fully and comparison has to take into account several factors.

Nuclear Materials useful for producing electricity

There are three elements which are useful for converting nuclear energy into electrical energy. The three elements are – Uranium-235, Plutonium-239 and Uranium-233. The number following the element name shows the total number of nucleons in nucleus . As we know, the number of protons in the nucleus, that is the atomic number, gives us name of that element. There are some elements which, of course, have the same number of protons, but different number of neutrons. They are called '*isotopes*' of the element. All isotopes of an element have the same atomic number, but different atomic mass.

We can now note that, two isotopes of Uranium, namely, Uranium-235 and Uranium-233, and one isotope of plutonium, namely, Plutonium-239, are the three elements which can conveniently be used to produce electricity. They are the fissile materials used to produce energy. Out of them, only Uranium-235 occurs naturally. The other two have to be produced artificially. Two other naturally occurring elements

help us as the source material for producing these two fissile elements. They are Uranium-238 and Thorium-232. These two elements are called '*Fertile material*', because they can give birth to fissile material.

Breeding the fuel

When Uranium-238 is bombarded with neutrons, it absorbs one neutron. Its atomic mass, thus, increases by one, but atomic number does not change. In the next step, the nucleus emits two electrons. Thus, in this second step, its atomic number increases by two, but atomic mass does not change. An electron emitted from the nucleus has very high energy and is called 'Beta Particle'. These two steps, that is absorption of one neutron and emission of two beta particles, taken together convert fertile material Uranium-238 into fissile material Plutonium-239. In a similar process Thorium-232 can get converted to Uranium-233.

Generating fissile material from fertile material by neutron bombardment is called '*Breeding*'. As we have seen, neutron bombardment can be used for producing energy by splitting the atoms. This is what is done in nuclear reactors. The same process of neutron bombardment can also be used for breeding, by having the fertile material kept alongside the fissile material, in nuclear reactors. The nuclear reactors, which carry out Breeding along with Fission are called '*Breeder Reactors*'.

Naturally occurring Uranium recovered by mining and processing, consists of several isotopes of Uranium. Uranium-235, which is fissile, is only about 0.7 % of the total quantity of natural Uranium. Most of the remaining Uranium is made up of its Uranium-238 isotope. When we bombard natural uranium by neutrons, Uranium-235 undergoes fission and produces energy. The Uranium-238, which is fertile, gets converted into Plutonium-239 which is fissile.

Alhad G. Apte

Shri Alhad G. Apte completed his B.E. (Electrical) course from Walch and College of Engineering, Sangli as a rank holder from Shivaji University, Maharashtra. He joined Bhabha Atomic Research Centre (BARC) as Scientific Officer in the year 1972.

During the tenure in the BARC, he held important portfolios in the BARC and served for 40 years. Computer Networks, Cybersecurity, Supercomputing, Grid Computing are his areas of specialization. He superannuatedin 2012 as Outstanding Scientist and Head of Computer Division of the BARC. He also chaired Computer and Information Security Advisory Group of Department of Atomic Energy.

He undertook and completed several projects at Department of Atomic Energy (DAE) level and at national level, including classified projects. He has worked on Cyber Security related consultative committee of International Atomic Energy Agency of United Nations. He was closely involved with CERN, Geneva, and European Commission for projects in Grid Computing.

He joined,in 2012, as Senior Advisor, National Technical Research Organisation (NTRO), India's Technical Intelligence Agency, under the Prime Minister's Office. He served as the Chief of NTRO and Ex-officio Secretary to Government of India, from 2013 to 2015.

He is a writer on Science and keenly involved in music. He has written several articles in 'Vishwakosh', the Marathi Encyclopedia of Government of Maharashtra. His common man's book on telecommunication in Marathi, 'Sandeshayan' was published by 'Granthali' in 1998. He has authored in Marathi the widely acclaimed extensive chronicle of Atomic Energy in India'BharatachiAnugatha', published by ManovikasPrakashan in May 2017. He has translated, in poetry form, the Krithis of Kannada Saint Purandardas in Marathi. A music album of Meera Bhajans composed by him was released in Mumbai in March 2017.